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Effect of high magnetic field on recrystallization behavior of cold rolled H70 brass

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Abstract. Effect of high magnetic field annealing on recrystallization behavior of cold rolled H70 brass was investigated. Specimens were annealed with and without a 12T magnetic field at different temperatures, respectively. The results showed that the recrystallization fraction of field-annealed specimen is lower than that of the non-field annealed specimen, while the percentage of ∑3 grain boundaries is higher than that of the non-field annealed specimen. The analysis results indicate that the high magnetic field hinders the recryatallization of cold rolled H70 brass, but promotes the formation of ∑3 grain boundaries. This may attributed to the formation of large number of asymmetric grain boundaries under the high magnetic field decreases the grain boundary migration process which leads to the slower of recrystallization process and makes the special grain boundary have more chance to grow up under the magnetic field.

1. Introduction

In recent years, the electromagnetic processing technology has been widely used in the solid phase transformation of materials. Researchers have paid many attentions to reveal the relationship between high magnetic field and the recrystallization behavior of the deformation alloys. Most researches in this field are related to magnetically affected recrystallization in ferromagnetic materials [1-3]. With the development of high magnetic field technologies, researchers found that non-ferromagnetic metals which almost have no reaction in the conventional magnetic field heat treatment are also quite sensitive under the high magnetic field. In 2003~2010, Molodov and his collaborators [4-9] explored the magnetically affected recrystallization and grain growth in non-ferromagnetic metals, and the results showed that the magnetic annealing can substantially affect the texture and grain structure evolution during recrystallization and grain growth in magnetically aluminum, zinc, titanium and zirconium. In 2008, Sheikh-Ali and his coworkers [10] found that the microhardness of diamagnetic pure copper, after the high magnetic field heat treatment, was higher than the specimen annealed without the magnetic field, they attribute it to the prevention of high magnetic field on the reduction of dislocation density in the specimens. In 2015, He et al [11-12] studied the effect of high magnetic field annealing on the recrystallization texture evolution in cold-rolled pure copper, and they found that the magnetic field annealing promotes the formation of the recrystalliation Cube texture in cold-rolled pure copper sheets. These researches have progressed the understanding of the high magnetic field mechanism on recrystallization in non-ferromagnetic metals. However, till now minimal work has been conducted to study the grain boundary character in non-ferromagnetic metals under the high magnetic field. In the present work, the recrystallization and grain boundary character of cold rolled H70 brass induced by the high magnetic field are discussed.

2. Materials and method

The material used in this study was a 50% cold-rolled commercially H70 brass plate, with a chemical composition of (wt%): 68.5.0～71.5 Cu, ≤0.03 Pb, ≤0.002 Sb, ≤0.5 Ni, ≤0.10 Fe, ≤0.002 Bi, ≤0.3 impurity, Bal. Zn. Specimens with the dimensions of 10mm×15mm×1mm were cut from the cold-rolled H70 brass plate, and were subjected to isothermal annealing at 300 °C, 400 °C, 500 °C and 600 °C for 30min, respectively, in a furnace installed in a cryo cooler-cooled superconducting magnet at a heating rate of 5°C /min, and then cooled in the furnace. During the magnetic annealing, a 12T magnetic field was applied during the whole heating and cooling processes. The specimens were placed at the center of the applied field with their rolling direction (RD) parallel to the magnetic field direction (MD).

Microstructures of longitudinal sections of the specimens were examined by orientation imaging microscopy (OIM). The scan was carried out over the area of 817×612 measuring points with a 0.25 μm step size. The percentage of recrystallized regions and ∑3 grain boundary were calculated using the Channel 5 software.

3. Results and discussion

Figure 1 shows the OIM maps of the specimens annealed at different temperatures with and without the high magnetic field. In these OIM maps, both the rolling direction and the magnetic field direction are horizontal. As figure 1 show, when annealed at 300°C, compared with the non-field annealed specimen, there still remains a small amount of deformation bands in the field annealed specimen. When the annealing temperature is higher than 400°C, the deformation bands completely disappear, and the grain size of the annealed specimens' increases obviously.

Figure 2 shows the recrystallization percentage and ∑3 grain boundary percentage of the specimens annealed at different temperatures, with and without the magnetic field. As figure 2(a) shows, the recrystallization percentage of field and non-field annealed specimens shows upward trend with the increase of annealing temperature. Compared with non-field annealed specimens, the recrystallization percentage of field annealed specimens are all lower than that of the non-field annealed specimens at the same annealing temperature. This indicates that high magnetic field annealing hinders the recrystallization of cold rolled H70 brass. As figure 2(b) shows, the percentage of ∑ 3 grain boundary of annealed specimens raises rapidly with the increase of annealing temperature. Compared with the non-field annealed specimens, the ∑ 3 grain boundary percentage of field annealed specimens is higher than the corresponding non-field annealed specimens at the same annealing temperature. This indicates that the high magnetic field promotes the formation of ∑3 grain boundaries.

During the magnetic field annealing, the diamagnetic brass interacts with the external magnetic field. Under the action of high magnetic field, the electron orbital of diamagnetic brass will change, and will produce a small magnetic field opposite to the direction of the external magnetic field, which will resist the action of external magnetic field.

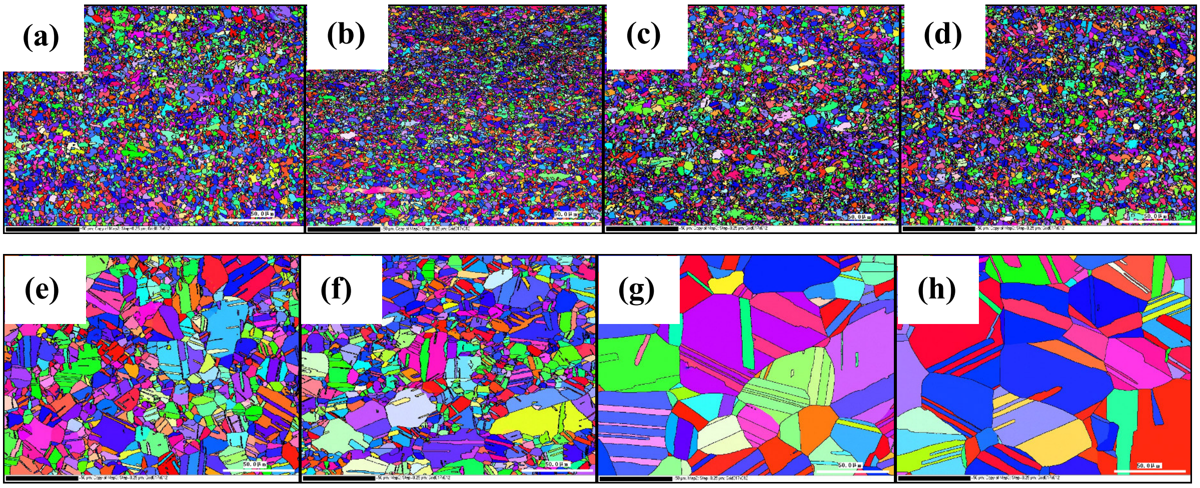

Figure 1. OIM（IPF+ Grain boundary）maps of specimens annealed at different temperatures. (a) 300°C, B=0T; (b) 300°C, B=12T; (c) 400°C, B=0T; (d) 400°C, B=12T; (e) 500°C, B=0T; (f) 500°C, B=12T; (g) 600°C, B=0T; (h) 600°C, B=12T

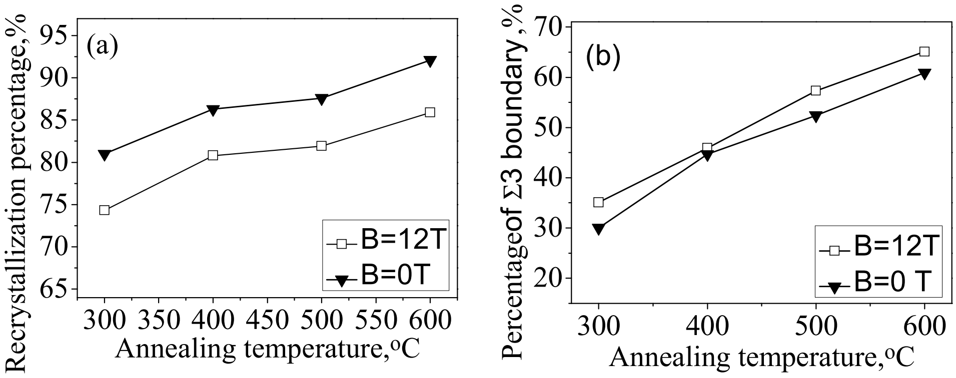

Figure 2. The percentage of recrystallized regions (a) and ∑3 grain boundaries (b) in specimens annealed at different temperatures.

During the process of recrystallization, grain growth depends on the grain boundary migration process. For the recrystallization process under the high magnetic field, the movement of the grain boundary is influenced simultaneously by dual role of interfacial tension and magnetic force. Interfacial tensions at the grain boundary respectively point to the center of adjacent two grains, and their directions are opposite. While the magnetic force act at the grain boundary is related to the direction of the external magnetic field, its direction is fixed. So these two forces in different directions acted at the same grain boundary will make the boundary bend and redirect, thus the originally symmetrical grain boundary plane will become asymmetric tilt under the action of high magnetic field. Researches of Molodov [6] showed that the movement speed of bending tilt asymmetric grain boundaries during the annealing process is slower than the symmetric boundary under the same conditions. So, for field annealed specimens, the formation of a number of tilt asymmetric boundaries makes boundary migration become slow, so that recrystallization process becomes slow compared to the non-field annealed specimens. At the same time, ∑3 CSL grain boundary has lower boundary energy compared with the random boundaries, under the high magnetic field, the grain boundary migration becomes slow, which make the special grain boundary groups have more chance to grow up. However, under the condition of non-field annealing, most of the grain boundaries (mainly high-energy large angle grain boundaries and slightly high-energy special boundaries) are in the metastable state. A large number of grain boundaries migrate at the same time, the growth of low-energy special grain boundaries is limited. Therefore, compared with the non-field annealed specimens, the percentage of ∑3 grain boundary in field annealed specimens are higher.

4. Conclusion

The effect of high magnetic field annealing on recrystallization behavior of cold rolled H70 brass process was studied. The results showed that the recrystallization fraction of field-annealed specimen is lower than that of the non-field annealed specimen, while the percentage of ∑3 grain boundaries is higher than the non-field annealed specimen. It indicates that high magnetic field annealing hinders the recrystallization process of H70 brass, but promotes the formation of ∑ 3 grain boundary.

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